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Improving the production technology of drilling and blasting operations by blasting of high ledges

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Abstract. In modern economic conditions, the issue of improving the efficiency of mining enterprises is very relevant. One of the key processes isdrilling and blasting operations (DBO), which determine the efficiency of the entire complex of mining operations. One of the main methods of controlling the explosion energy is the diameter of the blast wells. According to the recommendations of prof. B N Kutuzov the diameter of blast wells is correlated with the fracturing and strength of the exploding rocks. With increasing blockage and rock strength to achieve the required quality of explosive crushing preference is given to drilling equipment with a small diameter of wells. By blasting of high ledges, especially large-block rocks with a strength coefficient of more than 15 on the M M Protodyakonov scale; the use of high-performance drilling equipment for drilling small-diameter blast wells is difficult. This is due to the fact that the calculated value of the resistance line along sole (RLAS) does not pass the safety condition for drilling the first row of wells. In this regard, the paper proposes and justifies the use of extensions of the lower parts of wells using mechanical expanders.

1. Introduction

In quarries of construction, materials for drilling explosive wells with a diameter of up to 200 mm in rocks of medium and strong strength are used machines with submerged pneumatic hammers. There are mainly machines of domestic and foreign production [1, 2]:

- URB-2A with a diameter of 120–190mm blast wells;
- Sandvik (D25KS, D245S) with a diameter of blast holes 127–203 mm;
- TAMROCK (PANTERA 800, PANTERA 900, PANTERA 1100, PANTERA 1500) with the diameter of blast wells 115–152 mm;
- Atlas Copco (ROC 460 PC, ROC F7, ROC F9, ROC L6, ROC L7) with blast hole diameters of 105–165 mm;
- FURUKAWA (HCR 1000-1200-1500, PCR200) with the diameter of blast wells 65–150 mm.

This drilling equipment is used in quarries with a ledge height of 10 meters or less. By increasing the height of the ledge to 12–15 m or more, drilling the first row of wells in large-block rocks of medium and above average strength with a small diameter does not provide a condition for safe drilling, since the calculated values of the resistance line along the sole do not pass the condition for safe drilling of the first row of wells.

In this situation are the following methods and technologies for drilling and blasting operations recommended [2–4]:

- use of larger diameter wells (if this type of drilling equipment is available);
- the use of boiler charges (difficulty in creating boiler cavities, uneven crushing) or mechanical extensions along the length of the well (increased consumption of drilling the first row of wells);

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- use of inclined wells drilled parallel to the slope of the ledge (presence (absence) of this type of drilling equipment at the enterprise; difficulty in ensuring the safety of inclined wells with large volumes of drilling and blasting operations; difficulty of loading and installation of the explosive network, especially in the absence of mechanization; high wear of drilling equipment);
- increase of the charge energy of explosives (type of explosives, specific consumption of explosives);
- use of paired-converged wells (increased drilling expenditure of the first row of wells).

Currently a lot of mechanical expanders are designed for blast wells, which can be installed on existing drilling equipment as well as on auxiliary equipment and allow drilling small-diameter blast wells up to 250 mm or more.

The analysis of the considered methods of explosive crushing intensification in the conditions of Krutorozhinsky field of gabbro-diabase son PAO ‘Orsk quarry management’ has shown the applicability of mechanical expansion of explosive wells to ensure the safe drilling of the first row of wells [5, 6]. Therefore, the problem emerges of substantiating the parameters of expanded well cavities.

2. Methods of research

To determine the rational parameters of the location of blast wells, we suggest using the principle of self-similarity, based on taking into account the critical displacement rates of the array in the zone of action of adjacent borehole charges [5–11]. The proposed principle of self-similarity is well established in calculating the parameters of the location of borehole charges in underground conditions [7].

3. Main part

The study of rational parameters of drilling and blasting operations was carried out in conditions of Krutorozhinsky field of gabbro-diabases on PAO ‘Orsk quarry management’. The parameters of the quarry and development system are shown in Table 1.

Table 1. Main parameters of the quarry and development system.

Parameters	Value
Design depth of the quarry, m	80–200
Length of the quarry on top, m	1870
Width of the quarry on top, m	800
Design height of the ledge, m	15
The angle of slope of the working ledge, the degree	75
The minimum width of a working platform, m	34–60

At the Krutorozhinsky quarry, the following types of explosives are used in waterlogged, partially waterlogged and dry wells (Table 2).

Table 2. Characteristics of the used explosives.

Characteristics for types explosives	Heat of explosion, kJ/kg	Volume of gaseous explosion products, l/kg	Bulk density, g/cm^3	Detonation speed, m/s
Grammonit 79/21	4291	895	0,85–0,90	3200–3600
Grammonit 30/70	3977	800	0,85–0,90	3800–4500
AS-25P	3200	910	1.00	4600–4800
Arsenit ГБ-1	4100–4200	820–850	0,75–0,85	4500–5100
Arsenit ГБ-2	4270–4750	850–860	0,75–0,85	4800–5500
Arsenit ГБ-4	4300–4500	790–820	0,75–0,80	5000–5200
Fortis	3260	968	1.00	5100
MS-U-1	5700–5800	710–895	0.65–0.75	6700

For these types of explosives were the rational values of the resistance line along the sole at the height of the ledge of 15 m and the diameters of wells of 150 and 190 mm for rocks of different strength and fracturing determined (Table 3).

Table 3. Values of the rational resistance line on the sole, m.

Diameter of well, mm	The fortress of rocks on the horizon							
	f=8	f=10		f=12		f=14		f=16
	Fracture category							
	II	III	IV	III	IV	III	IV	V
explosives – MS-U-1 (K_{VV}=0.83)								
150	6.1	4.8	4.1	4.9	4.3	4.8	4.1	3.5
190	6.7	5.4	4.5	5.5	4.7	5.3	4.6	3.9
explosives – Arsenit GB-2(K_{VV}=0.98)								
150	6.7	5.3	4.5	5.4	4.7	5.3	4.5	3.8
190	8.2	6.6	5.5	6.7	5.8	6.5	5.6	4.7
explosives – Arsenit GB-4 (K_{VV}=1)								
150	6.6	5.3	4.4	5.4	4.6	5.2	4.5	3.8
190	8.2	6.5	5.5	6.6	5.7	6.4	5.6	4.7
explosives – Grammonit 79/21 (K_{VV}=1)								
150	6.3	5.0	4.2	5.1	4.4	4.9	4.3	3.6
190	7.7	6.2	5.2	6.3	5.4	6.1	5.3	4.4
explosives – Arsenit GB-1 (K_{VV}=1.05)								
150	6.5	5.2	4.3	5.2	4.5	5.1	4.4	3.7
190	8.0	6.3	5.3	6.5	5.6	6.3	5.4	4.6
explosives – Grammonit 30/70 (K_{VV}=1.09)								
150	6.0	4.8	4.0	4.9	4.2	4.7	4.1	3.4
190	7.4	5.9	5.0	6.0	5.2	5.8	5.1	4.3
explosives – Fortis (K_{VV}=1.21)								
150	6.3	5.0	4.2	5.1	4.4	5.0	4.3	3.6
190	7.8	6.2	5.2	6.3	5.5	6.1	5.3	4.5
explosives – emulsion composition AS-25P (K_{VV}=1.25)								
150	7.0	5.6	4.7	5.7	4.9	5.5	4.8	4.0
190	8.6	6.9	5.8	7.0	6.1	6.8	5.9	5.0

The minimum allowable value of the resistance line along the sole under the conditions of safe placement of drilling equipment for drilling the first row of wells is 6.0 m.

According to calculations the mechanical expansion of blast wells should be used only in large-block rocks with a strength coefficient of more than 10 on the M M Protodiakonov scale.

To determine the rational parameters of mechanical expansions of blast wells, we propose the use of the principle of self-similarity [5–7, 12], which is based on the account of the critical displacement rates of the array in the zone of action of adjacent borehole charges [13, 14].

The voltages generated by the explosion of a borehole charge are determined by [5–7, 12]:

$$\sigma_{сж(р)} = \rho_0 C_p V_{сж(р)} \tag{1}$$

where $\sigma_{сж(р)}$ – acting compressive (tensile) stresses, Pa;

ρ_0 – specific mass of rock, kg /м^3;

C_p – speed of spread of a longitudinal elastic wave in mountain (sample), m/s;

$V_{сж(р)}$ – the displacement rate of the mountain under the action of compressive (tensile) voltages, m/s.

Hence the critical displacement rate of the mountain is defined as: [5–7]:

$$V_{кр}^{сж(р)} = \frac{\sigma_{сж(р)}}{\rho_0 C_p} K_д \tag{2}$$

where $K_д$ – coefficient of dynamism.

The mountain will be destroyed if the resulting array offset rates exceed or equal the critical values:

$$V_{сж(р)} \geq V_{кр}^{сж(р)} \tag{3}$$

where $V_{сж(р)}$ – the displacement rate of the mountain under the action of compressive (tensile) dynamic voltages, m/s;

$V_{кр}^{сж(р)}$ – minimum (critical) values of the displacement rate of the mountain, when destruction occurs, due to compressive (tensile) voltages, m/s.

The resulting explosion displacement rates of the array at this point are determined by [5–7]:

$$V_{сж(р)} = k_\nu \bar{r}^{-\nu} \tag{4}$$

where k_ν – seismic proportionality coefficient depending on elastic parameters of the destroyed rocks [9, 10].

$$k_\nu = \sqrt[3]{\frac{C_p}{9\rho_0}\left(\frac{1+\mu}{1-\mu}\right)^2} = \sqrt[3]{\frac{C_p}{\rho_0}\left(1-\frac{4C_p^2}{3C_p^2}\right)^2} \tag{5}$$

where μ – coefficient Puasson's;

$\nu = 2{,}25$ – indicator of degree;

$\bar{r}$ – equivalent reduced distance, $\mathrm{m/kg}^{1/3}$.

Equivalent reduced distanceis determined by [6, 12]:

$$\bar{r} = \frac{r_n}{\sqrt[3]{Q_{eqv}}} \tag{6}$$

where r_n– distance from the test point to the center of gravity of the equivalent charge, m;

Q_{eqv} – the equivalent charge weight, kg.

According to rock properties of Krutorozhinsky field the critical displacement rates of the mountain (m\s) are shown in Figure 1, at which the destruction of the mountain occurs.

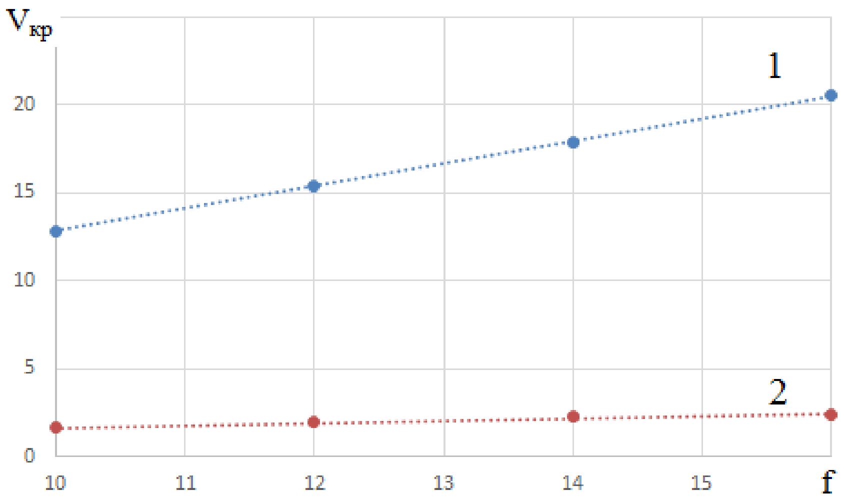

Figure 1. The value of the critical displacement rates of the array from the rock fortress:
1 –critical speed under the action of compressivevoltages;
2–critical speed under the action of tensile voltages.

Mechanical expanders with a diameter of 250 mm were used to calculate the parameters of borehole charge extensions.

Depending on the strength of the rocks and the corresponding critical displacement rate of the array, the optimal value of the reduced resistance line along the sole ($\mathrm{m/kg}^3$) is determined Figure 2.

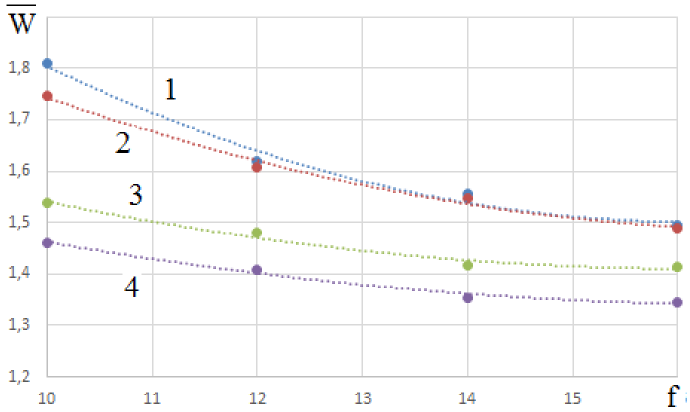

Figure 2. Dependence of the reduced RLAS from the coefficient of rock strength
1 – Grammonit 79/21; 2 –MS-U-1; 3 – Arsenit G-1; 4 – emulsion composition AS-25P.

The obtained dependencies are approximated by a polynomial equation of the form:

$$\bar{W} = \alpha f^2 - \beta f + \gamma \tag{7}$$

where $\overline{W}$ – rational reduced value of the resistance line along the sole, m/kg^3;
f – the strength coefficient;
α, β, γ – empirical coefficients, the value of which is shown in Table 4.

Table 4. Value of empirical coefficients.

Type of explosives	α	β	γ
Grammonit 79/21	0.008	0.26	3.60
MS-U-1	0.005	0.17	2.96
Arsenit G-1	0.003	0.11	2.30
Emulsion composition AS-25P	0.002	0.09	2.08

The length of mechanical expansion of borehole charges (lp, m) is shown in Figure 3.

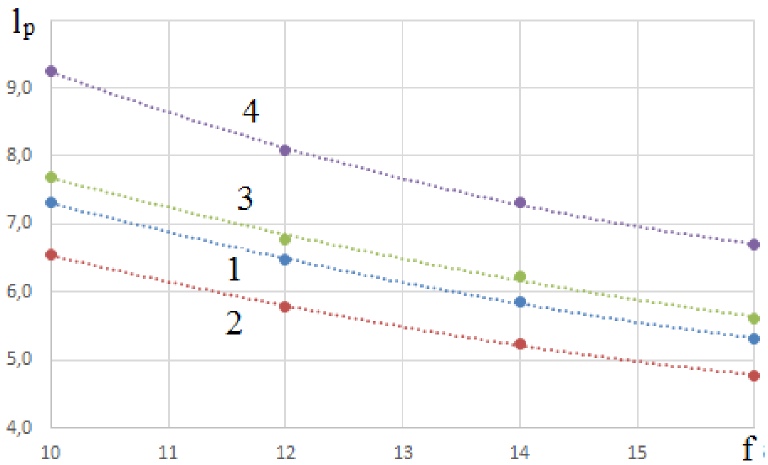

Figure 3. Dependence of the length of the mechanical expansion of the well from the rock strength
1 – Grammonit 79/21; 2 – MS-U-1; 3 – Arsenit G-1; 4 – emulsion composition AS-25P.

The paper defines the parameters of drilling and blasting operations using mechanical extensions of the lower parts of wells, with a ledge height of 15 m and a well diameter of 150 mm for large-block rocks of medium and high strength.

4. Conclusion

The application of a method for determining the parameters of mechanical extensions of borehole charges based on the principle of self-similarity, based on the comparison of critical displacement rates of the array allows:

1.Increase the yield of blasted rock mass from one linear meter of wells, especially in medium and hard-to-explode rocks by 15–26%, by increasing the grid of wells, in comparison with inclined wells and wells with a diameter of 250 mm, both when exploding to a free surface, and when interacting with adjacent charges, exploding with deceleration;

2. Reduce the specific consumption of explosives by 8–23% in large-block hard rocks compared to wells with a diameter of 250 mm.

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